MECHANICAL RESPONSE OF ANKLE LIGAMENTS WITHIN PHYSIOLOGIC LOADS

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INTRODUCTION:
The purpose of the study is to measure the mechanical response of isolated ligaments of the human ankle. There have been several studies that have measured the ultimate strengths of ankle ligaments but this study compares the mechanical response of ankle ligaments within physiologic loads. The viscoelasticity of a ligament’s mechanical response is an important aspect of its physiological function and should be investigated. Much has been written about the biomechanical characteristics of ankle ligaments in general but most studies have focused on ultimate strengths.

METHODS:
Eight fresh frozen ankles (mean age 65) were dissected of all superficial tissue to expose the ligaments surrounding the joint. Eight ankle ligaments were retrieved from each specimen by meticulously detaching them from their bony origins. The ligaments included: Medially - Anterior and Posterior Tibiotalar (ATT & PTT), Tibiocalcaneo (TC); Laterally – Anterior and Posterior Tibiofibula (ATaF, PTaF), Anterior and Posterior Talofibula (ATAF, PTAF), Calcaneofibula (CF). One ATT, one TC and two ATaF ligaments were damaged during retrieval and were not included in the study. The ligaments were frozen in gauge soaked with phosphate-buffered saline (PBS, pH 7.4).

Before testing the ligaments were thawed to room temperature. 5mm was used as the testing gauge length for all ligaments. The ligaments were immersed in a warm water bath (~37°C) and tested in a Mach-1™ Micromechanical testing system (Biosyntech, Quebec, Canada). This system measures loads in grams for specimens up to a few centimeters in length. First the unpreconditioned ligament was subject to a step test (30% strain, 60 sec relaxation). Preconditioning was then performed (10 steps @30% strain). Immediately following the preconditioning a step test was performed (30% strain, 180 sec relaxation). This was followed by 20% and 10% step strains with 20 minutes rest between (each held for 180 sec). After the tests the ligament thickness and width was measured.

RESULTS:
Hysteresis curves plotted for each specimen showed the ligaments to be preconditioned within 10 cycles. Stress Relaxation curves were obtained from each step test and plotted for each type of ligament. The stress relaxation varied among different ligaments. The TC ligament relaxed up to 50% of the maximum load at 30% strain and was found to be the ligament that relaxed the most over the different strain levels. The peak loads were evaluated for the 30% strain step test and ranked as follows (from highest to lowest): CF, ATaF, PTAF, TC, ATiF, PTiF, ATT and, PTT. The strain energy at 30% strain ranked (from highest to lowest): CF, ATaF, TC, PTAF, ATIF, ATT and, PTT (Figure A). The strain energy at 10% strain ranked (from highest to lowest): TC, CF, ATT, ATaF, PTT, PTAF, ATIF and, PTF (Figure B).

DISCUSSION:
In the past ligament testing has been conducted with bone-ligament-bone complexes. This was mainly due to difficulty in obtaining the specimens and the potential for slippage in the testing machine. The ligament loads during this study were never higher than 5N, therefore negating the need for complicated mounts and bulky equipment. The 5mm gauge length resulted in deformations of up to a maximum of 1.5mm (30% strain) then 1mm (20%) and 0.5mm (10%). A study that looked at strain measurements of the lateral ankle ligaments showed that the ATaF ligament was the most highly strained lateral ligament. Up to a maximum of 20% strain was recorded during plantar flexion with internal rotation. This strain value represented a 1.6mm change in length for the ligaments in that study. Therefore, the maximum change in length (1.5mm) used in this study was less than the maximum strain one could expect during normal ankle motion.

Strain energy gives an indication of the ability of a ligament to absorb energy; these results show that the lateral ligaments have the ability to absorb more energy than the medial ligaments at 30% strain. However, at lower strain levels (10% strain) the medial ligaments tended to absorb more energy than the lateral ligaments. At 10% strain the highest loads were still recorded in the lateral ligaments. Indeed, the mechanical response of the medial ligaments in general is more linear than the lateral ligaments at lower strains. This may be a result of the in-vivo experiences of the medial ligaments. Since the shape of the trochlear surface of the talus has a larger lateral radius of curvature than the medial, the movement on the medial side is less than that experienced on the lateral side during dorsi/plantar flexion. This suggests that the lateral ligaments experience larger variations in length. It follows then that at high strain levels the medial ligaments would tend to relax more quickly than the lateral ligaments. For this study it is the TC ligament that relaxed the most, up to 50% of the maximum load at 30% strain. In comparison, the CF ligament relaxed only 43% at the same strain.

Since most studies on ankle ligaments have focused on ultimate strengths the results reported here are significant. Understanding the way ligaments behave within physiological strains is of paramount importance. It has been shown here that the lateral ligaments are well adapted to their unique position in the ankle complex. It is often suggested that since the lateral ligaments are commonly reported as being the most injured ligaments they must be sub-standard in some way. The lateral ligaments tested in this study showed a great ability to absorb energy (more than the medial ligaments) at high strain. They also displayed good relaxation ability compared to the medial ligaments. The medial ligaments were found to be the thickest and broadest of the ligaments in this study and this is consistent with anatomic studies of the past.

Soft tissue balancing in total knee arthroplasty is an important procedure. It has recently been recognized that in total ankle arthroplasty ligament balancing is of equal importance. Understanding the ligaments’ behavior and getting the balance right may very well contribute to the success of the implant. This study contributes to the understanding of ligament behavior within physiologic loads.